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ABSTRACT

Effects of microcomputer-based laboratory (MBL) exercises and level of cognitive development on high school biology students' ability to construct and interpret line graphs were investigated. Forty-six students enrolled in general biology classes at a rural high school volunteered to participate in the study. These students were administered instruments to assess the level of cognitive development and line graphing ability. Twenty students were chosen to participate in the study. Experimental students experienced four laboratory exercises that used a microcomputer to gather, display, and graph experimental data. Contrast students experienced the same four laboratory exercises using conventional laboratory equipment and produced line graphs by hand. Effects due to instructional method were found on the assessment of the students' graph construction and interpretation abilities. Students experiencing MBL exercises outperformed the contrast students on graph interpretation tasks. Students experiencing conventional laboratory exercises outperformed the experimental students on graph construction tasks. Effects due to cognitive development were indicated, with those students classified as high cognitive development outscoring those classified as low. Interview data revealed that students applied prior knowledge and experience to the conditions presented by the graph and were led to erroneous conclusions about what the graph actually represented. The students also reached improper conclusions about the interpretation of graphs when they improperly scaled axes. (TW)

The Effects of Microcomputer-Based Laboratory Exercises on the Acquisition of Line Graph Construction and Interpretation Skills by High School Biology Students

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Introduction

Computers have been available for instructional use for well over two decades. They have been traditionally used for software-interactive situations not making use of the microcomputer as a tool. It is evident that these uses did not tap the true power of the microcomputer (Berger & Wells, 1985/86). The situation was seen by Thomas (1983) as being analagous to using a programmable calculator as a paper weight. It would certainly do the job but so would a brick.

A recent educational use of the microcomputer has been to interface it with probes to collect experimental data in the science laboratory (Eisele, 1982). This new use has been designated microcomputer-based laboratory exercises or MBL for short. Utilized in this manner, the microcomputer can perform tasks that either cannot be conveniently done by students, like collecting data over the weekend or overnight, or tasks that are usually considered to be dull or boring such as recording data point, drawing graphs, or timing intervals. Students no longer have to rely on devices such as thermometers, stopwatches, data tables, and hand-drawn graphs. By using MBL equipment, they can easily and accurately measure, store, and graphically display such physical quantities as temperature, position, velocity, acceleration, sound, light, force, and physiological indicators such as heart rate and blood pressure (Thornton, 1985). Such graphic presentations of experimental data can make the student-conducted experiments more accurate, efficient, and meaningful (Graef, 1983) and have always been the preferred medium for scientists, mathematicians, and engineers (Mokros & Tinker, 1986).

The data collected in MBL activities can be viewed by the student, stored on disk, or printed out for laboratory reports. The students are not just passive recipients of this data, but are activley involved in its collection. They are constantly making choices about parameters and display methods for each experiment. For example, the minimum and

maximum values to be collected, the type graph on which to display the data, the scale of that graph, and the amount of time to collect data must all be decided upon and input by the students. Once they have made these decisions and run the experiment, they may change their minds about the parameters when they see the data displayed. Since the parameters in MBL exercises are as easily changed as a misspelled word is corrected using a word processor, this is not a difficult situation for MBL students.

MBL activities pair in "real time" events with their symbolic representations. This aspect of the activities allows students to have the opportunity to watch the graph being produced as the experiment progresses. They have both the abstract representation (the graph) and the concrete objects (the experiment) together in what has been termed an "immediate abstraction" by Naiman (1986; in Mockros, 1985). Since many high school students are still developing cognitively, having a concrete example of the abstract representation may be very useful. It may be of some use in bridging the gap between concrete and formal operations (Mokros, 1985).

As a whole, MBL exercises provide students with a genuine scientific experience and have, according to Tinker (1986), the potential for contributing to an extremely powerful learning experience (in Mokros & Tinker, 1986). It is hoped that MBL will positively influence the way students: 1) communicate the data obtained from laboratory experiments; 2) interpret the data they receive from the experiments of others (i.e. charts and graphs in their textbooks); and 3) value laboratory exercises. If MBL follows the traditional model of computer-assisted instruction, the quantity and quality of students' work as well as problem solving skills will improve.

Purpose

This study investigated the effects of microcomputer-based laboratory exercises and level of cognitive development on students'

ability to construct and interpret line graphs. Two methods of conducting laboratory activities, MBL and conventional, were investigated. The MBL students used a computer to collect, display, store, and print the graphically presented data from their exercises. The only time they used ordinary paper and pencil was to answer questions about their exercises. The conventional students used traditional equipment (i.e., stopwatches, thermometers, and data tables) to collect and graph their data. Students in the MBL group conducted simple laboratory exercises that asked them to heat or cool various solutions and to produce and interpret graphs of the data. Students in the conventional group conducted identical exercises and produced graphs by hand from the data collected.

The setting of the study was clinical in nature. This setting allowed for the collection of both qualitative and quantitative data. Each student was interviewed individually and tested individually during the study.

Method

Forty-six students enrolled in general biology classes at a rural high school in north Georgia during the 1986-87 school year volunteered to participate in the study. These students were tested by their classroom teacher just prior to the start of the study to assess level of cognitive development, attitude toward laboratory work and computers, and graphing ability. Based on scores on these measures, twenty students were chosen to participate in the study. All twenty students were indiviudally interviewed about graphing strategies and feelings towards laboratory work. The twenty students chosen were assigned to either high or low cognitive development groups depending on their score on the Group Asessment of Logical Thinking (GALT) (Roadranka, Yeany, & Padilla, 1983) instrument. The low group had students with GALT scores from zero to three. The high group had students with GALT scores from six to ten. Students in the two cognitive developmental groups were then assigned to experimental or contrast groups based on their scores on the Test of

Graphing in Science (TOGS) (McKenzie & Padilla, 1986) and their sex. A matched design that maintained a balance of GALT and TOGS scores and gender was achieved (see figure 1). Once these group assignments were made, a one-hour session was held with individual students to aquaint them with their respective laboratory equipment.

The laboratory exercises conducted by the students had been pilot tested with both science educators and practicing teachers. Changes were made in the laboratory exercises to remove concerns these experts had about procedures and communication. The revised exercises were submitted to a panel of five science educators to determine appropriateness and completeness of the four-exercise package. The panel was asked to comment on the parallel nature of the tasks the two groups were asked to perform. The panel concluded that the exercises were parallel, appropriate, and provided ample practice on graphing skills.

All students then completed four, one-hour laboratory exercises that were confirmed by the cooperating teacher to be novel experiences for the students. Ten experimental students completed laboratory exercises using a computer interfaced with probes for the collection and display of data. Ten contrast students completed the same four laboratory exercises using stopwatches, thermometers, and data tables to collect data.

Graphs for the experimental group were provided by the computer. All contrast students constructed their graphs by hand on standard graph paper. All exercises for both groups used water and/or ice along with a Bunsen burner. The laboratory worksheets the students completed as a part of the laboratory exercise contained no questions about content. The tasks completed by the student on the worksheets involved answering questions about data or relationships displayed on their graphs.

Qualitative data were collected during all laboratory sessions. This data consisted of taped conversations and comments between students and field notes taken during the laboratory exercises.

Students' ability to construct and interpret line graphs was

	L	H	Total
M	2 males 3 females $\bar{X}$ GALT - 1.8 $\bar{X}$ TOGS - 12.8	3 males 2 females $\bar{X}$ GALT - 8.0 $\bar{X}$ TOGS - 15.2	5 males 5 females $\bar{X}$ GALT - 4.9 $\bar{X}$ TOGS - 14.1
C	2 males 3 females $\bar{X}$ GALT - 1.6 $\bar{X}$ TOGS - 11.6	3 males 2 females $\bar{X}$ GALT - 8.2 $\bar{X}$ TOGS - 17.4	5 males 5 females $\bar{X}$ GALT - 4.9 $\bar{X}$ TOGS - 14.6

Level of Cognitive Development

L - Low
H - High

Instructional Strategy

M - Microcomputer-based Laboratory Exercises
C - Conventional Laboratory Exercises

Figure 1
Group Characteristics

individually assessed following the above mentioned treatments using an open-ended version of the TOGS instrument called I-TOGS. This open-ended version was designed for use on an individualized basis and not as an assessment of an entire class. The level of content, type of content, and type of task was not changed. The only difference in the I-TOGS instrument was that there were no multiple-choice items. The student had to physically perform the desired task, not simply choose a letter. The I-TOGS had been submitted to a panel of four science education experts for an opinion as to the parallel nature of the tasks. In its final form, they agreed that the instrument was asking the student to do the same task asked for in the original TOGS instrument.

All students were subsequently interviewed about the reasons for their responses on the graphing instrument. To determine the effects of practicing line graph construction, the experimental students completed a supplemental graphing task. After completing the tasks, they were asked to make any corrections they wished on their copy of the I-TOGS instrument.

Analysis of variance and covariance procedures were used to identify quantitative treatment effects with graphing ability serving as the dependent measure. Because of the small number of students, an alpha level was not preset. We decided to look at the data carefully and decide the risk factor associated with a Type I error. Qualitative data analysis procedures were employed to answer qualitative research questions and add richness to the data. Trends were identified in student responses to give a clearer picture of how students view graphs and graphing.

Research Design

In this study, students were assigned to either the experimental or contrast group. All assignments were made using matching procedures to help assure a more comparable group than would have been possible with random assignment of twenty students.

Using Campbell and Stanley (1963) notation, the research design is as follows:

$O_1 \quad O_2 \quad O_3 \quad O_4 \quad X_1 \quad O_5 \quad O_6 \quad O_7 \quad X_3 \quad O_8$

$O_1 \quad O_2 \quad O_3 \quad O_4 \quad X_2 \quad O_5 \quad O_6 \quad O_7$

01 = Interview data (pre)

02 = Attitude (pre)

03 = TOGS

04 = GALT

X1 = MBL activities

X2 = Conventional exercises

05 = I-TOGS

06 = Interview data (post)

07 = Attitude (post)

X3 = Supplemental graphing

08 = I-TOGS review

Results

Statistical analysis of the data indicated an effect ($p \leq .106$) due to instructional method on the graph construction and interpretation abilities of tenth grade biology students (see Table 1 & Table 2). Students experiencing conventional microcomputer-based laboratory exercises outperformed the conventional students on graph interpretation tasks (see Table 3). Students experiencing conventional laboratory exercises outperformed ($p \leq .10$) their experimental counterparts on graph construction tasks (see Table 3). No difference in their attitude towards laboratory work was noted (see Table 4).

Effects related to cognitive development were indicated with those students classified as high cognitive development outscoring those classified as low ($p \leq .05$). This was true for graph construction and interpretation tasks but not for attitude towards laboratory work. The attitude towards laboratory work was not different for the two cognitive level groups (see Table 5, Table 6, & Table 7).

Table 1

Analysis of Covariance Summary for Effects Due to Instructional Method on Graph Construction Achievement as Measured by I-TOGS (Post-Assessment)

Source of Variation	dF	Mean Square	F	p
Instruction Method	1	8.98	3.25	.09
Covariate (TOGS-R) (Construction Score)	1	5.03	1.82	.20
Error	17	2.76		

Table 2

Analysis of Covariance Summary for Effects Due to Instructional Method on Graph Interpretation Achievement as Measured by I-TOGS (Post-Assessment)

Source of Variation	dF	Mean Square	F	p
Instruction Method	1	5.92	2.81	.11
Covariate (TOGS-R) (Interpretation Score)	1	49.84	23.68	
Error	17			

Table 3

Means Across Instructional Methods
for All Measures
(n=20)

	Microcomputer-Based Laboratory Exercises (n=10)		Conventional Laboratory xercises (n=10)	
Measure	$\overline{X}$	SD	$\overline{X}$	SD
Graphing Achievement				
TOGS Total	14.1	4.10	14.6	5.08
TOGS-R Total	11.2	4.42	11.4	4.97
TOGS-R Construction	3.6	1.35	3.6	2.01
TOGS-R Interpretation	7.6	3.44	7.8	3.39
Graphing Achievement				
I-TOGS Total	17.2	3.83	17.6	3.30
I-TOGS Construction	6.2	1.96	7.6	1.39
I-TOGS Interpretation	11.0	2.30	10.0	2.09
Cognitive Development				
GALT	4.9	3.51	4.9	3.76
Attitude Towards Laboratory Work				
Pre	75.0	7.06	79.1	11.16
Post	79.2	9.24	78.3	12.36

Table 4

Analysis of Covariance Summary for Effects Due to Instructional Method on Attitude Towards Laboratory Work

Source of Variation	dF	Mean Square	F	p
Treatment	1	80.5	1.61	.22
Covariate Attitude Instrument (Pre)	1	1211.3	24.16	.001
Error	17	50.13		

Table 5

Analysis of Variance Summary for Effects Due To Cognitive Development on Graph Construction Achievement as Measured by I-TOGS (Post-Assessment)

Source of Variation	dF	Mean Square	*F*	*p*
Cognitive Level	1	20.81	9.34	.007
Error	18	2.28		

Table 6

Analysis of Variance Summary for Effects Due to Cognitive Development on Graph Interpretation Achievement as Measured by I-TOGS (Post-Assessment)

Source of Variation	dF	Mean Square	*F*	*p*
Cognitive Level	1	33.54	10.54	.005
Error	18	3.22		

Table 7

Analysis of Variance Summary for Effects Due to Cognitive Developmental Level on Attitude Towards Laboratory Work

Source of Variation	*dF*	Mean Square	*F*	*p*
Cognitive Level	1	5.00	.042	.84
Error	18	118.8		

No two-way interactions were found by analysis of covariance. This was true for graph construction and interpretation as well as attitude towards laboratory work (see Table 8, Table 9, Table 10).

The supplemental graphing exercises completed by the experimental students had no apparent effect. The students made virtually no corrections on their I-TOGS instrument. Therefore their score showed no increase.

Qualitative data indicated that the students had no precise way to label graph axes. Student responses to items on the I-TOGS instrument that required them to label axes showed a random pattern of assigning dependent variables to the y-axis and independent variables to the x-axis. This occurred across both individual tests and the group as a whole. Student interview data gave more convincing evidence of this. Responses typical of the eighteen students who exhibited axis labeling problem are given below.

> "I don't know. It could be either way. I mean I do it either way. There ain't no right way or is there? I don't know."

> "I'm going to put the number of blossoms on the left because I always try to put stick the littlest number up there."

> "You just label them however you want."

> "I think it would be easier to put the weight of the chicken on top and the number of eggs. . . . I really don't know. I wondered if there was a set way to do it."

> "I think you could do it either way, couldn't you?

It was also evident that the students believed a best-fit line was a connect-the-dots line. Students' responses on the I-TOGS instrument and their laboratory worksheets inducated that all twenty students connected the plotted points on the graph with a line. They made no attempt to draw a line that would represent a general trend in the data. There was, however, evidence that they might know that here might be another way to

Table 8

Two Way Analysis of Covariance Summary for Effects Due to Instructional Method and Cognitive Developmental Level on Graphing Construction Achievement as Measured by I.-TOGS

Source of Variation	dF	Mean Square	F	p
Instructional Method	1	8.98	4.38	.054
Cognitive Level	1	16.14	7.87	.013
Instruction Method X Cognitive Level	1	.0	0.0	.97
Covariate (TOG-R) (Construction)	1	5.03	2.45	.138
Explained	4	7.54	3.67	.028
Error	15	2.05		

Table 9

Two-Way Analysis of Covariance Summary for Effects Due to Instructional Method and Cognitive Developmental Level on Graph Interpretation Achievement as Measured by the I-TOGS Instrument (post-assessment)

Source of Variation	dF	Mean Square	F	p
Instructional Method	1	5.70	2.96	.106
Cognitive Level	1	6.82	3.55	.079
Instruction Method X Cognitive Level	1	.14	.07	.79
Covariate (TOG-R) (Interpretation)	1	49.84	25.93	.001
Explained	4	15.68	8.16	.001
Error	15	1.92		

Table 10

Two-Way Analysis of Covariance Summary for Effect Due to Instructional Method and Cognitive Developmental Level on Attitude Towards Laboratory Work

Source of Variation	dF	Mean Square	F	p
Instructional Method	1	80.58	1.45	.25
Cognitive Level	1	5.95	.11	.75
Instruction Method X Cognitive Level	1	9.59	.17	.68
Covariate (Pre-test)	1	1211.3	21.72	.001
Explained	4	326.8	5.86	.005
Error	15	55.8		

draw the line. It was noted in a comment by Nancy who said "The line is bumpy but we could straighten it out with regression." Only one student exhibited changed behavior very late in the experiment. She made an attempt at a line that did not connect all the dots and it did resemble a best-fit line.

Typical student responses during their interview substantiate the observed behavior. Several are given below.

"Just draw the line to connect all the dots."

"The best-fit line would be dot-to-dot. You know, connect them."

"I suppose that a best-fit line means it touches all the dots."

"Okay. A best-fit line, I just connected the dots."

"Connect the dots. That's the easiest thing."

It was also indicated that when students constructed graphs, they did not believe a line to represent the data was necessary. Examination of written material provided by students during the laboratory exercises and assessment instruments indicated that students infrequently drew a line of any type to represent the data. They simple left it out. When the total number of times they did draw a line was compared to the number of times they were asked to perform the task, it was found that they drew a line less than 30% of the time. Student comments about this occurrence are given below.

"I just plotted the points. I didn't do nothing else. I just left them."

"I plot the points. (prompt: And leave them?) Yeah."

"Then I'd plot the points. (prompt: Anything else?) No."

Qualitative data also indicated that students apply prior knowledge and opinions to the conditions of a graph. Tinker (1986) has indicated the possibility that students use personal opinion when interpreting

graphically presented relationships. The graphs in question usually present situations and data that may not represent experiences that are part of a student's knowledge base.

When students in this study were pressed for an interpretation of data presented on a graph, they resorted to personal experiences and opinions to explain the results. This behavior was exhibited by thirteen of the twenty students. The interpretation they came up with was logical for them but was not based on the data presented in the graph. Selected comments made by the students are given below.

> In a graph that presented data about the number of eggs laid by chicken and the number of hours of light they received, students said:
>
> "And if there were no light, it would probably be about 100 (eggs) because there, its like there'd be enough light, because they're not completely dark. . . if you've ever been in one."
>
> "Zero. Yeah you know, if it doesn't have any light it can't produce."
>
> In a graph about the amount of water and the growth of a plant, students said:
>
> "It would probably be that graph because if you give a plant that much water, it would die."
>
> "I would say 5 because it would be depending on what type plant it is. It's too much water."
>
> In a graph concerning the number of eggs produced and the weight of the chicken, a student said:
>
> "The chickens that had already laid eggs would be lighter I guess."
>
> In another graph about the use of heating oil and the ambient temperature, a student said:
>
> "I mean it has to be logical. As the temperature is rising, you're not going to use the same amount of heating oil."

Qualitative data also indicated that the students also reached erroneous conclusions about the interpretation of graphs when they

improperly scaled axes. Examination of both the I-TOGS instrument and student work during the laboratory exercises revealed that students do not regard the proportional scaling of axes as important or necessary. The resulting interpretation of the graphs was not correct because the relationship displayed by the graph was but should not have been linear. Selected comments support this point.

"Iwould just put the numbers. On the bottom it would be 40, 360, 915, and 1430 and 16, 34, 56, 64 on the side."

"It would just be the numbers 10, 13, 17, 20, and 24."

"If you want the honest-to-goodness truth, I would put the exact numbers."

"Yeah, if you use the exact numbers, you won't have to go in-between."

"Putting the exact data numbers, makes the graph more accurate."

The graphs produced by twelve of the students indicated the intended non-linear relationship as a straight line with an approximate slope of one. When asked about the nature of the relationship, they said:

"Yeah, you know, as you goes up the other goes up."

"It's easy to see that the points are increasing about the same."

"They both go up. They're sort of the same."

Discussion

Statistical analysis of quantitative data from the graph construction portion of the I-TOGS instrument provided evidence of a difference in the graph construction abilities of students experiencing either MBL or conventional laboratory exercises. The group experiencing conventional laboratory exercises performed better on the construction portion of the assessment instrument. It is therefore reasonable to assume that the conventional exercises did a better job of providing students with graph

construction skills than did the MBL exercises. An effect size of -0.74 was calculated fr .n the scores on the construction portion of the I-TOGS instrument. This effect size represents an educationally significant difference between the two groups and indicates that line graph construction by hand is worth the effort and should be pursued in the teaching of graph construction.

This is a logocal result stemming from the nature of the two treatments. The conventional laboratory group had a great deal of practice on line graph construction tasks. The MBL group had little practice performing graph construction tasks. Although they scaled axes, chose time intervals, and decided ranges, the computer provided the graph construction functions for the student. There was no evidence of any emphasis on graphing in the science curriculum for the tenth grade. Consequently, this may have been the only practice the students had with graphing since their physical science classes (cooperating teacher's response).

The fact that the students who had more practice on graph construction tasks outperformed those students who did not is not surprising. It has been a long-term tenant of education to allow students to learn by doing.

The supplemental graphing treatment the MBL students received after the experimental treatment allowed these students to have as much practice on graph construction tasks as the conventional students. This supplemental treatment did not result in a substantial increase in their scores on the construction portion of the I-TOGS instrument. There may have been a factor to account for the apparent non-effect. The students involved in this study encountered a large number of graphs and did a great deal of graphing in a relatively short time. They voiced a "burned-out" feeling when they were asked to spend several hours constructing and interpreting more graphs. They all performed the required tasks on the supplemental treatment because they were individually given and

monitored until they were completed. There was, however, less control on the time and effort students spent on identifying and correcting errors on the I-TOGS instrument. Most students spent only five to ten minutes looking over their copy of the instrument. They could not be forced to do any more. When asked if they were finished, they would respond "Yes". When prompted "Are you sure?", they would again respond positively. There was no way to be sure they had put forth as much effort on the final task of correcting the instrument as they had in completing it originally.

Examination of the data from the graph interpretation portion of the I-TOGS instrument provided evidence of a difference in the graph interpretation ability of students experiencing MBL and conventional laboratory exercises. Students experiencing MBL laboratory exercises are better at performing graph interpretation skills than those students experiencing conventional laboratory exercises. An effect size of 0.48 was calculated from the scores on the graph interpretation portion of the I-TOGS instrument. This effect size is educationally significant and indicates that the learning that occurred on graph interpretation skills during exposure to MBL exercises was worth the time and effort to implement it.

This finding is in line with statements put forth by many proponents of MBL exercises. Studies by Brassell (1985) (in Mokros and Tinker, 1986) have shown that students' confusion about interpreting slope and height on graphs seems to be resolved in a very short time with MBL exercises. Studies dealing with acceleration (Mokros and Tinker, 1986) have shown that students not only learn about interpreting acceleration graphs but they are resistant to incorrect challenges by their instructor. These previous studies dealt with a specific area of graph interpretation. The results from this study are more generic and offer evidence that microcomputer-based laboratory exercises are useful in general graph interpretation instruction.

When the MBL students were asked to use graph interpretation skills

on the I-TOGS instrument, they had a "minds' eye" picture of laboratory events that were not available to the students conducting laboratory exercises in the conventional manner. They could realistically remember what the line on a graph did when they heated water or added ice to the water. It is not unrealistic to expect students to be able to transfer this picture or their knowledge about how a graph should look to other similar situations. They would know, for instance, that if something increased (water temperature), then the line on the graph should go up, and would be able to apply that to another situation where something else increased (i.e. number of rabbits). They would then realize that both lines would go up because they both increased in some parameter.

The conventional students had no such "minds' eye" picture of the laboratory experiment and results. The only thing they saw move up or down was the mercury level in a thermometer. While available for all to see, this action was usually only witnessed by the person designated to watch the thermometer and to "call-out" temperatures at the appropriate time intervals.

Statistical analysis provided evidence that there was a difference in the graph construction ability of students that was attributable to level of cognitive development. Those students classified as high cognitive developmental level showed a higher score on the graph construction portion of the I-TOGS instrument than did low cognitive developmental students. This evidence supports the earlier contention by authors such as McKenzie (1983), Padilla et al., (1983), Wavering (1983) (in McKenzie, 1983), and Culbetson and Power, (1959) who pointed to a relationship between graphing ability and cognitive development.

Graph construction tasks seemed to be performed by students using a set of rules or algorithms. They would plot points by going "out" and then "up". They labelled axes by intervals from the smallest to the largest value. These rules or algorithms are evidently better or more correctly established in students of higher cognitive developmental level and would

allow them to more correctly construct graphs. They can evidently also apply these rules to more situations and arrive at correct answers more often than students of low cognitive developmental level.

As with graph construction, statistical analysis has shown a difference in the graph interpretation abilities of students with differing levels of cognitive development. The students of higher cognitive developmental level scored higher on the graph interpretation portion of the I-TOGS instrument than did the low cognitive developmental students. This is in line with the research cited in the previous section.

When students are asked to interpret graphs, they may have no good algorithm to help them with the interpretation as they do with construction. Every graph they encounter on an assessment instrument may represent a different relationship. They lose the benefit of a precise set of rules to apply in almost every case. They must instead rely on their own observation and reasoning ability. They must be able to mentally represent the relationship shown by the graph and formulate it into an interpretation they can understand and possibly put into words. These words can then communicate what the graph means to another person or it can be used to match a written description to determine its accuracy.

Statistical analysis of data from the instrument measuring student's attitude towards laboratory work revealed no difference in the mean scores of the two groups. The majority of students in the study, regardless of treatment group, had a positive attitude towards the laboratory. Their comments during interviews about their responses to items on the instrument gave insight as to why they felt positive about the experience.

The overwhelming reason that students gave for liking laboratory work was that the atmosphere was one where they felt relaxed and in control. They said they did not feel the pressure to remain still or quiet and they felt good in the laboratory. They said they enjoyed being able to move around, look around, and interact with other students in their class.

Most students have experienced many laboratory exercises by the time they reach the tenth grade. Like any attitude, an attitude towards laboratory work would necessarily be influenced by prior participation and success in laboratory. The influence due to prior experience was evident in the administration of the Attitude Towards Laboratory Work instrument prior to any experimental activities taking place. This influence was still evident after the treatments were completed. Students would even refer to their responses on the pre-treatment administration of the instrument. This was taken as an indication of the influence of laboratory exercises before the time frame of the study.

Attitudes are not changed overnight and are usually resistant to change over small time frames (Simpson, 1985). This study lasted nine weeks, but the individual students were only exposed to the instructional method for four class periods. This short time exposure, along with a small number of students, may acount for the MBL students, while being ahead on their mean scores on the instrument, not showing a difference that is statistically demonstrable.

An interesting change in the attitude of the students was noted in the eperimental students that was not assessable by the quantitative attitude instrument. This observation was only possible with the qualitative methodologies utilized in this study. The attitude change exhibited by the students was in how the computer should be used in the laboratory.

When the MBL students began the laboratory exercises, they did the same things as the conventional laboratory group. They sat and watched the computer collect the data in much the same way they would watch a thermometer. This behavior changed over the course of the second exercise. During this exercise, the students began to let the computer do the data gathering without their watching. When asked why they changed their behavior, they said that they trusted the computer to do a good job. Nevertheless, they still watched it start. "Just to make sure." they said. They began to use the, now available, extra time to complete the

laboratory sheet or perform other necessary tasks. By the fourth laboratory exercise, students attitude towards the computer seemed to be that it was a type of tool. They seemed to see its role as one to perform tasks for them and give them time to perform other tasks not possible to do with the computer (i.e. fill out the labsheet) They no longer felt that they must watch or do every task. They felt that the computer would take care of the assigned tasks and they could make more efficient use of their time.

Qualitative Data Discussion

The first assertion that came from the data was that students have no precise way to label graph axes. This assertion was based on the data from eighteen of the twenty students taking part in the study. These students never mentioned the concept of independent or dependent variables as a way to label graph axes. Of the two students who did not provide data to support this assertion, one student said that the y-axis was labelled with what you measured and another hinted at the idea but did not arrive at such a stable response. The pattern that the eighteen students exhibited was that it did not really matter which variable went with what axis. They often said that they wondered if there was a right or proper way, but it did not seem to bother them to just label them so that the points would be easy to locate or plot. In essence they said they wanted to label the axes the way the numbers were given to them.

The convention that the dependent or responding variable should go on the y-axis is one that could be easily corrected. The students acted and sounded as if no one had ever told them of this procedure.

A second assertion to arise was that best-fit lines are connect-the-dots lines. This is not totally surprising. Students have been connecting the dots in pictures since they were old enough to draw. They did it for entertainment in early school years and were probably told to do so in many situations in mathematics classes (or possibly not told not to

do it). It is logical to expect students to extend this practice to points on graphs in science classes.

All twenty students in the study failed to use a best fit-line when constructing a line graph. They all used connect-the-dots lines as a way of expressing the trend in the data whenever a line was drawn on the graph. All students did express a great deal of curiosity in what was meant by a best-fit line. When they were asked to do this task on the I-TOGS, their response was "What do you mean by a best-fit line?". A meaningful response was never given. The curiosity level became so high that I am convinced that the students were beginning to ask other teachers, students, or parents what a best-fit line was. It almost became a greeting. Even with this high level of curiosity, only one student changed the connect-the-dots line to an "almost best-fit line" when asked to look over the I-TOGS after the supplemental graphing treatment. The line was drawn but when asked about it, she responded "I really don't know what it is but I think that is the way to draw it".

Students may not have suffered gradewise from drawing a connect-the-dots line. A connect-the-dots line does not totally hide or destroy a trend in data points. If the points are going up, then more than likely the connect-the-dots line will also show the rising trend in the data. The students who do this are not necessarily penalized. They may still understand the point the teacher is emphasizing and may get the answer correct on a quiz. What they may miss are the relationships displayed by the data. They may totally miss linear, logarithmic, or other relationships common in scientific data. Thay also do not get the opportunity to understand that multiple data points may be represented by a single point on the graph and that the line that passes through a distribution of points does so in a specific mathematical procedure. In short, it seems that they are not being exposed to concepts that may be beneficial in later schooling or life.

The third assertion that came to light logically follows the previous

one. This assertion was that students do not believe a line to represent the data is necessary. The students would draw a line only when asked. They evidently did not know what it meant, and it did not make the graph any easier to understand. It was not a task they saw as useful or beneficial.

The best-fit line is normally used to show a trend in the data, but it is also useful to interpolate between data points. Students do not need a best-fit line to accomplish this task. They simply use the values for the points closest to the one they are asked to interpolate to get an answer. They would compute a proportion between the numbers and estimate what the value would be. Again, the students may not have penalized on many assignments that required them to interpolate between data points. Their answers were close enough for the teacher and how they got them may not have been important.

An assertion dealing with interpretation also came from the data. This assertion was that the students apply personal opinion when interpreting the graph and are led to erroneous conclusions. The students who exhibited this behavior missed much of what they were supposed to gain from the graph. In cases involving extrapolation of data or continuing the line past the data points, the students did not follow the previous trend in the data. Instead, they used their own experiences. While this was logical for the students, the interpretation that they had of the graph was many times incorrect. They found it easier to guess about the interpretation and then defend the guess along lines that were familiar to them.

The students did not seem to understand that the graph was unique and applied to only that particular experimental situation. They would try to fit the graph to something they had personally experienced. This resulted in the students drawing conclusions about the data that were not always valid. The students would misinterpret a change in slope being due

to conditions outside the experiment and not to the experimental parameters.

A second assertion dealing with interpretation arose. This one stated that improper scaling of the graph axes produced graphs that would lead to improper interpretation. The students tended to be successful in scaling the axes when the numbers presented to them were single digit or small. The students would scale the axes by one's, two's, or five's for the entire range and proceed to plot the points. This was not the case when the number were very large and very unequal spacing. These axes tended to be labelled with the numbers given.

The students would miss the relationship between the variables when the axes were improperly scaled. When they just put the number on the axes and plotted the points, the points would indicate a more or less linear relationship. This was very evident when they were asked to plot an exponetial relationship. Instead of scaling the axes properly, the numbers were usually placed in equally spaced intervals.on both axes and the points plotted. They would miss entirely the curving line characteristic of an exponential relationship. The students were oblivious to the fact that the observed relationship changed if the scaling was improper. They were more concerned with plotting the points accurately than proper scaling.

The emphasis they placed on accuracy of plotted points probably stemmed from the emphasis of proper plotting of points in mathematics classes. They knew how to maximize the plotting accuracy and that was their concern.

Conclusions

Based on the results presented in this paper, the following conclusions seem appropriate.

1) Conventional laboratory exercises that allow students to practice graph construction skills result in higher student achievement on graph construction tasks.

2) Microcomputer-based laboratory exercises that collect and present experimental data to students as "real time" graphs result in higher student achievement on graph interpretation tasks.

3) Graph construction and interpretation tasks are influenced by cognitive developmental level.

4) The students in this study did not understand how to label and scale axes.

5) The students in this study did not understand the concept of a best-fit line.

Implications

The findings from this study have implications for the teacher who wishes to use microcomputer-based laboratory material in high school science classes. Although these results were obtained from students in a clinical setting, they should still be applicable to normal laboratory situations. The students always worked in small groups, used typical laboratory sheets, and performed structured experiments. It should be very easy for a teacher to modify existing laboratory exercises to allow the collection and display of data to be handled by a computer. The questions the students would be responsible for answering could possibly be at a higher level and more complicated since the time to collect the data would be drastically reduced.,

It seems that an approach that allows students the opportunity to practice graphing skills in some phase of the instruction would be beneficial. This would lead to an integrated approach for MBL exercises. An introduction, practice, or review of graphing skills in the instructional setting both before and during the unit would most likely maximize the benefits. It would be very unfair to the student not to get instruction in basic graphing skills during the use of MBL exercises. It would be as unfair as asking a student to rely on hand-held calculators in mathematics class before the student had mastered basic mathematical skills.

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